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The advent of multibeam bathymetry systems, which are capable of total seafloor ensonification, have made fundamental changes in hydrography. The new IHO S-44 standards challenge hydrographers to achieve even greater depth and position accuracy with multibeam systems. ORCA has made incremental improvements in each of these areas as demonstrated in a series of at sea survey tests. Improvements have been made to the system that allow collection of data during turns, an order of magnitude improvement in heading measurement, and accurate measurement of vessel depth with respect to mean sea-level. Data collection during turns was achieved using a sensor that integrates inertial and GPS signals. Heading accuracy has been improved by going from a gyro based measurement system to a dual-antenna GPS phase differencing system. In addition to more accurate placement of soundings, especially in the outer beams, the system components are smaller and require less power than those replaced. Vessel depth measurements are made with a high-frequency altimeter, which also yields sea surface information including wave height, period, number and direction. An autonomous surveying capability has been developed to achieve the desired ensonification of the seafloor without over or under surveying an area. Coverage is based on the quality of data in the outer beams and the desired overlap in coverage. This paper describes the sensor and software changes made to the ORCA, and provides comparative results from system testing.

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IMPROVED SURVEY ACCURACY WITH ORCA

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Abstract

The advent of multibeam bathymetry systems, which are capable of total seafloor ensonification, have made fundamental changes in hydrography. The new IHO S-44 standards challenge hydrographers to achieve even greater depth and position accuracy with multibeam systems. ORCA has made incremental improvements in each of these areas as demonstrated in a series of at sea survey tests. Improvements have been made to the system that allow collection of data during turns, an order of magnitude improvement in heading measurement, and accurate measurement of vessel depth with respect to mean sea-level. Data collection during turns was achieved using a sensor that integrates inertial and GPS signals. Heading accuracy has been improved by going from a gyro based measurement system to a dual-antenna GPS phase differencing system. In addition to more accurate placement of soundings, especially in the outer beams, the system components are smaller and require less power than those replaced. Vessel depth measurements are made with a high-frequency altimeter, which also yields sea surface information including wave height, period, number and direction. An autonomous surveying capability has been developed to achieve the desired ensonification of the seafloor without over or under surveying an area. Coverage is based on the quality of data in the outer beams and the desired overlap in coverage. This paper describes the sensor and software changes made to the ORCA, and provides comparative results from system testing.

Introduction/Background

NRL's Mapping, Charting and Geodesy Branch has been conducting research and development in oceanographic sensor technology and survey techniques for the Oceanographer of the Navy on the ORCA Program since 1994. Program policy guidance has emphasized the need for cost effective advanced technology using autonomous sensors, techniques and vehicles to rapidly characterize an area. A constant thread through each phase of the program has been improvement in data quality and survey efficiency. Ultimately the program goals are to develop a robust organic environmental data collection platform for use off of surface combatants.

The main vessel used for the developments has been the Oceanographic Remotely Controlled Automaton (ORCA).[1] ORCA is a 25 foot diesel powered semi-submersible instrumented with a SIMRAD EM 950 Multibeam, and associated motion compensation and telemetry systems. Data collected by the ORCA is radio telemetered to a host ship typically within 1 to 3 miles. Once on the host, data is processed in real time and survey products are generated at the completion of the day's survey.

In 1996 NRL teamed with the Naval Surface Weapon Center to build an "Oceanographic" variant to the Remote Minehunting System (RMS) referred to as the RMSO[2]. RMSO, see figure 1, is similar to ORCA in concept with added endurance and enhanced supportability. The vehicle will be delivered in early 1999. The sensor suite developed, improved and demonstrated on ORCA will be integrated on the RMSO. The RMSO is envisioned as an organic environmental collection platform for combatants, or as a force multiplier for T-AGS 60 class survey ships.

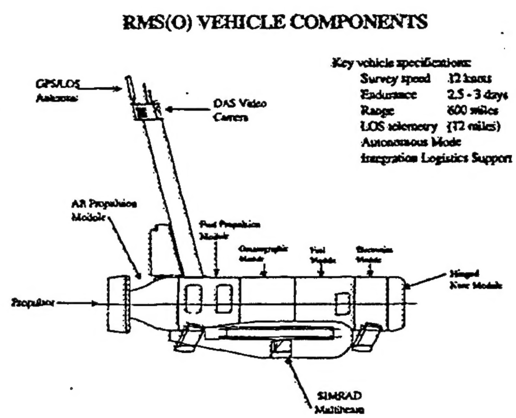

Figure 1

Numerous at sea tests have been conducted with the ORCA over the past four years. Initially, trials were conducted to test, and demonstrate the

multibeam and other sensor capabilities on such a small platform.[3] Later tests conducted showed the vehicle's stability and data quality to be equivalent or better than that of platforms 70 m and greater in length and adequate to meet Naval Oceanographic Office shallow water hydrographic survey requirements.[4] More recently, tests have been conducted to develop and demonstrate environmentally adaptive autonomous surveys.[5]

Each sea test spawned new ideas for improving data accuracy and survey efficiency. For example, visually noted variations in vessel depth with conflicting constant sensor depth read out led to more accurate draft sensing. Bathymetric sounding accuracy depends on the total error of the measurement system. Sources of system errors addressed by the program include draft, heading, roll, and position. Similarly, planning surveys with pre-selected survey lines resulted in holidays in some areas and over coverage in others. This problem led to the investigation of autonomous survey techniques where the next survey line is determined on-the-fly at the end of the current line which helps ensure the right coverage the first time. This paper provides an overview of the research and development in oceanographic sensor technology and survey techniques which have yielded more accurate data collected in less time.

IHO Standards

"In 30 years of surveying, 29 will have to meet International Hydrographic Office (IHO) Standards, and one will be for a crisis where good is okay. The majority of surveys are conducted for Safety of Navigation."[6] The new IHO Standards for Hydrographic Surveys, Special Publication No. 44,[7] describes four orders of surveys. The most stringent is "Special Order" which approaches engineering standards in critical areas where minimum underkeel clearance and bottom characteristics are potentially hazardous to vessels. "Order 3" is the least stringent intended for water depths greater than 200m and areas not covered by the previous orders. Employed properly, multibeam systems with the proper resolution and following the guidelines for quality control can be used to generate data adequate for all orders of surveys.

For illustrative purposes, IHO Standards for surveying a coastal area with an average depth of 30 m to Order 1 accuracy requires as a minimum:

<u>Horizontal Accuracy</u> (95% Confidence Level) = 5 m + 5% of depth

<u>Depth Accuracy</u> for Reduced Depths (95% Confidence Level)

error limits for depth accuracy = $\pm\sqrt{[a^2+(b*d)^2]}$

a = sum of all constant errors = 0.5m

b*d = sum of all depth dependent errors
where b = 0.013m
and d = depth

<u>Maximum Line Spacing</u> = 3 x average depth or 25 m, whichever is greater. If procedures for ensuring adequate sounding density are used, line spacing can be expanded.

For the 30 m case, the formulas yield a horizontal accuracy = 6.5 m, a depth accuracy of $\pm$.63 m and a line spacing of 75 m.

Depth Accuracy Improvements

Data in the Turns

In late 1997 ORCA modified its sensor suite to incorporate a POS-MV strap-down inertial system. The POS-MV utilizes a fiber optic gyro vertical reference unit and GPS (military, commercial or differential signal) coupled through a Kalman filter. This system allows survey data to be collected during vessel maneuvers. Earlier accelerometer based inertial systems were unable to survey during turns. The centripetal acceleration generated in a turn was interpreted as vessel roll and the survey data was adjusted for the "sensed" roll. This resulted in soundings being too shallow toward the inside of the turn and too deep on the outside of the turn. As a result, data collected during maneuvers did not meet specifications and were discarded. Typically the vessel had to maintain a constant heading for several minutes to allow the inertial system to settle out after executing a maneuver. The POS-MV eliminated this problem. The additional data in the turns also provides greater coverage and sounding density at the edges of the survey.

Vessel Draft

Problems with vessel draft were first noticed in 1995 while determining pitch and time-delay errors in Pensacola Bay. It was observed that vessel depth changed as a function of its speed and direction of travel, although the depth readout remained constant. The problem resulted from non-uniform flow occurring over the depth sensor pressure ports on the vehicle nose. Errors on the order of .5 m were observed. The ports were relocated only worsening the effect. A better method of determining vessel depth was needed.

NRL developed a "depthimeter" sensor that yields dynamic draft of the vessel. Traditionally, surveyors add a constant vessel draft to all soundings. It is known to vary; however, exact measurement had not been possible and, thus, a degree of error was accepted by setting the draft to a constant value. The "depthimeter" solves this problem by providing vessel draft at each sounding thus improving depth accuracy. Measurements made during the December 1997 ORCA trials reduced this component of the constant error to a negligible amount. Multiple surveys of the same area varying vessel speed and programmed depth from 1.5 m to 3.5 m resulted in 3.25 cm of depth error in 18 m of water from all sources of error including draft.

Horizontal Positioning Improvements

Heading Data

The outer beams suffer the most degradation due to the angular dependency of multibeam systems. In 100 m water depths using a swath of 7 times water depth, a heading error of 0.6° results in a horizontal position error of 3.7 m in the outermost beam. Until recently, ORCA used a Robertson SKR82 Gyrocompass which provided true heading to the multibeam and the ORCA Control Computer. The dynamic heading error of this gyro is 0.7° rms. x secant (latitude). At 45° latitude this corresponds to a worst case error of one half of the outermost beam's foot print size. In late 1997 a multi-antenna GPS heading system was installed on ORCA. This off-the-shelf system, integrated into the POS-MV, provides a heading accuracy of 0.05° with only a 1 m antenna separation, figure 2.

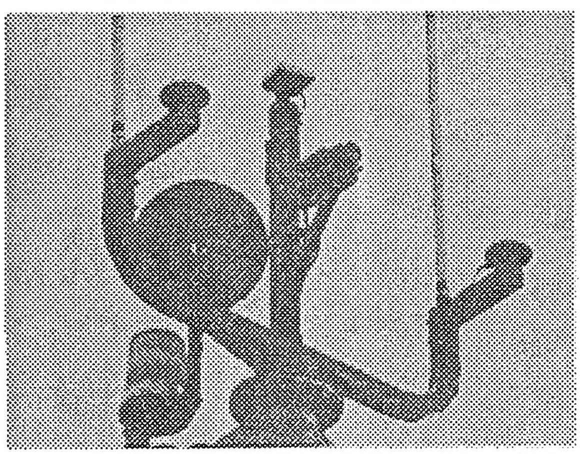

Figure 2

The system is more accurate and requires less power and space than the gyrocompass. The dual antenna GPS yielded an order of magnitude improvement in heading accuracy.

GPS

At first ORCA was equipped with a single frequency TRIMBLE GPS which was accurate to 40 m with out differential corrections, and 0.5 meters with corrections.[8] Field reports from the Naval Oceanographic Office indicated that single frequency GPS units were suffering unacceptably large position errors (as large as 50m at dawn and dusk) in equatorial zones, probably due to solar activity affecting the upper atmosphere. As a result NRL modified the ORCA to utilize a TASMAN dual frequency, differential capable GPS system.

The POS-MV inertial system provides best position by comparing DGPS and C(A) codes. Typically DGPS is more accurate; however, should it fail, the unit would select the C(A) code positions. Additionally, the position data is Kalman filtered resulting in superior positioning to stand-alone DGPS. The next step is to have TSS/Applanix modify the POS-MV to also accept GPS P code for " best position" comparisons.

Toward Better Survey Coverage Efficiency

A key research effort being conducted at NRL is the Real-time Tactical Response Initiative which includes Environmentally Adaptive Autonomous Surveys. The immediate goal of the autonomous surveying effort is to remove the human from the loop. The system allows the vehicle computer to monitor data quality and coverage assessment, generate navigational way points, and adjust sensor system operating parameters based on survey conditions. The goal is to perform cost effective surveys, neither over or under surveyed, performed in the shortest possible time while meeting IHO Standards.

Originally, surveys with ORCA were operator intensive, requiring a human operator to pre-plan survey lines and monitor survey progress to ensure adequate coverage. A standard multibeam survey involves driving several parallel lines with a desired overlap in the coverage areas for data verification. The system bottom coverage is affected by water depth, bottom slope, ambient noise and bottom reflectivity and these variables are not typically known in the planning phase. The hydrograper must periodically inspect displays that give clues to data quality and adjust trackline spacing and trackline orientation based on empirical observation and experience.

Dynamically adjusting tracklines based on data from the previous line minimizes survey platform on station time and cost. Data collected with parallel evenly spaced lines typically under samples or over samples the data, resulting in

inefficiency and /or loss of important data. As an example, consider adjacent lines of collected data: if the survey is being conducted properly there should be no gaps between the swaths of data from each survey line, and the overlapping areas of the two swaths should match in depth. If a problem exists it is immediately apparent from the display and corrective action can be taken to alter the survey track or adjust the appropriate instruments.

Methods to enable autonomous environmentally adaptive bathymetric surveying have been developed for ORCA. These methods perform real-time estimation of actual sonar system performance in terms of bottom coverage. 'Best-fit" curves are computed for the swath's edge, which effectively provides local smoothing of anomalous data. Given this edge estimate, the associated vessel trackline and operator specified desired percent bottom coverage, the algorithms generate waypoints for the next survey line utilizing actual vice predicted swath coverage. In its current implementation, the algorithms have been streamlined so that the next line's waypoints are generated during the end-of-line vessel turn, figure 3. During the December 1997 ORCA sea-trial a full 'hands-off' survey was successfully demonstrated. The operator specified the corner points of the region to be surveyed, and the adaptive survey system automatically generated the required waypoints and piloted the vessel through the entire survey.

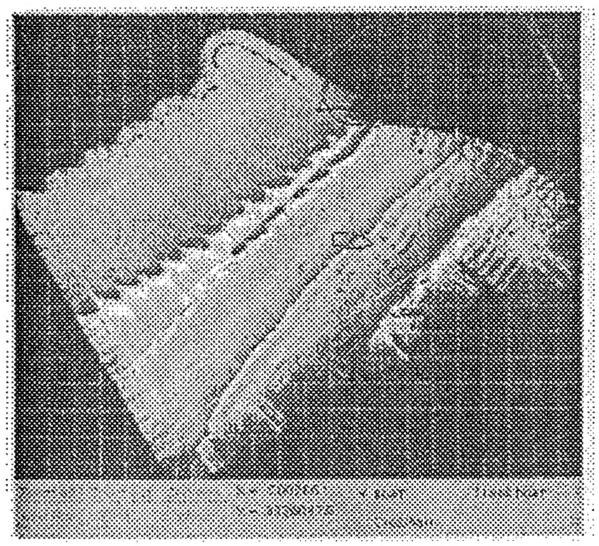

Figure 3

The ORCA program has demonstrated a 10% reduction in the time required to survey an area defined only by a polygon while improving survey efficiency and minimizing operator interaction. These techniques may prove to be a significant transition for the project by increasing survey efficiency resulting in a lower cost per square mile surveyed. The techniques are directly applicable to survey ships and are a critical step in the path to totally autonomous surveys from AUVs.

Conclusions

There is an emphasis in the new IHO Standards on the use of multibeam systems since they provide 100% bottom ensonification with soundings covering the entire seafloor. The accuracy of multibeam hydrographic surveys will never be as good as land mapping surveys; however, evolutionary improvements in sensors and survey techniques are narrowing the gap. Numerous improvements in the ORCA sensor system have improved its survey accuracy. This has included improvements in the positioning of soundings, reduction in the sum of depth errors, and survey coverage.

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References

[1] Bourgeois, B., Kalcic, M., and Harris, M., "ORCA – Oceanographic Remotely Controlled Automaton," The Hydrographic Journal, No. 79, January 1996.
[2] Harris and Bourgeois, "Battle Space Environmental Characterization with RMSO," 3rd International Technical Symposium, Technology and the Mine Problem, Apr. 1998.
[3] Bourgeois and Harris, "ORCA's Oceanographic Sensor Suite," IEEE Oceans '95, San Diego, Oct. 1995
[4] Reed, Johanson and Pope, "Pensacola Bathymetric Evaluation," Draft Report, Naval Oceanographic Office, 15 March 1996.
[5] Bourgeois, B. and Harris, M., "Autonomous Bathymetric Surveying," UUST Conference, 7-11 September 1997
[6] Gaffney, Paul ADM (USN), personal communication, 14 Nov. 1997.
[7] "International Hydrographic Organization Standards for Hydrographic Surveys, Special Publication No. 44," Fourth Edition, Monaco, 1998.
[8] Bourgeois and Harris, "The NRL "ORCA" Oceanographic Survey Vessel," UUST, Sept. 1995.